TRE-81-03

The Two Vehicle Concept for Overweight/Oversize Permits

Ontario

Ministry of
Transportation and
Communications

Policy
Planning and
Research Division

THE TWO VEHICLE CONCEPT FOR OVERWEIGHT/OVERSIZE PERMITS

A. C. Agarwal
Research Officer
Research and Development Branch

Published by:
The Policy Planning and Research Division
Ontario Ministry of Transportation and Communications
Hon. James J. Snow, Minister
H.F. Gilbert, Deputy Minister

This report may be reproduced, whole
or in part with attribution to the Ministry

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

Prepared for the
1981 RTAC Conference
Winnipeg, Manitoba

September, 1981

CONTENTS

	Page
1/ INTRODUCTION	1
2/ AXLE WEIGHT CONTROL IN HEAVY VEHICLES	3
2.1/ Equivalent Base Length Concept	3
2.2/ Ontario Bridge Formula	4
2.3/ Basis for Overweight Permit Vehicle Control	4
3/ TWO VEHICLE CONCEPT	6
3.1/ Limiting Criteria	7
3.2/ Analytical Development	8
3.3/ Worked Example	11
3.4/ Comparison with Tailgating Situations	11
4/ CONCLUSIONS	13
5/ REFERENCES	14
TABLE 1/	15
FIGURE 1/ Equivalent Base Length Concept	16
FIGURE 2/ Weight vs. Equivalent Base Length Diagram	17
FIGURE 3/ Tailgating by Heavy Vehicles on The Highway	18
FIGURE 4/ Vehicles With Legally Permissible Weights in Ontario	19
FIGURE 5/ The Two Vehicle Concept	20
FIGURE 6/ Minimum Required Distance	21
FIGURE 7A/ Special Permit Vehicles	22
FIGURE 7B/ Special Permit Vehicles	23

1/ INTRODUCTION

In 1971, the Ontario Ministry of Transportation and Communications introduced axle weight control for movement of the heavy commercial vehicles on Ontario Highways. This control facilitated an increase in the legal gross vehicle weight limits to levels significantly higher than those in most jurisdictions in North America.

The basis of the current legal limits prescribed in the Highway Traffic Act [1] is the Ontario Bridge Formula, which provides weight limit on a group of axles as a function of the individual axle weights and inter-axle spacings. The intent of the Ontario Bridge Formula is to provide maximum use of the highway system with minimum load-induced damage to the bridges and pavements. Within legal weight limits a maximum gross vehicle weight of 63 500 kg can be allowed over a maximum overall truck length of 21.0 m.

For practical, technical/economic reasons, the above limitations can be exceeded for heavy indivisible loads. The Highway Traffic Act enables the Ministry to issue special permits for transporting payloads which require vehicle configurations that do not comply with maximum gross vehicle weight/length limitations of the Highway Traffic Act.

During the early 1970's, the Ministry adopted a policy which stated:

> "Special Permits may be issued for carrying indivisible loads which are either overweight or overlength, but not both".

Upon applying this policy to actual special permit requests, it became evident that the policy discriminates against certain segments of the industry. Therefore, new, technically-grounded guidelines were required, in particular for the evaluation of vehicles transporting long, prefabricated, heavy objects such as pressure vessels, kilns, structural components, etc.

A careful review of the situation revealed that the Minsitry has two alternatives for resolving this problem:

1. Change the Ontario Bridge Formula to suit vehicles longer than 21.0 m.

This report contains the terms of reference and the development of the Two Vehicle Concept. A simple chart is provided and can be used for evaluating the permissibility of the single trip permit applications in the category of the Two Vehicle Concept. The evaluation procedure is illustrated by examples.

The special permit vehicles in the examples are compared with the potential cases of tailgating vehicles loaded within "legal" limits. The above procedure will also help a user to assemble a vehicle configuration most advantageous for him, while satisfying the requirements of the concept.

2/ AXLE WEIGHT CONTROL IN HEAVY VEHICLES

In 1967, the Engineering Research and Development Branch of the Ministry undertook to rewrite the terms of reference for heavy vehicle weight control in the province. The objective of this task was to develop a better understanding of the load-carrying capacity of Ontario's highway system and to establish the maximum operational load level for heavy vehicles.

It became clear at an early stage of the investigation that vehicles consisting of different axle weights at various inter-axle spacings are discontinuous loading functions and lead to very complex mathematical treatment. Therefore, a method was sought by which a vehicle could be transformed into an equivalent, continuous function suitable for mathematical treatment. This led to the development of the axiom of the Equivalent Base Length.

2.1/ Equivalent Base Length Concept

Equivalent base length, B_m as illustrated in Figure 1, is defined as the length over which the total weight on a group of axles can be uniformly distributed to cause force effects in a bridge structure similar to those caused by the group or axles. The formula for equivalent base length is:

$$B_m = \frac{4\Sigma \mid P_i x_i \mid}{\Sigma P_i} - \frac{2\,(N-1)}{bN}\left[\frac{\Sigma P_i x_i}{\Sigma P_i}\right]^2$$

where:

N = Number of axles in the axle group,

P_i = Weight on the i^{th} axle,

x_i = Distance of the i^{th} axle from the axle closest to the centre of gravity of the axle group,

and b = Base length of the axle group (the distance between the first and last axles of the axle group).

The above equation can be applied to a vehicle, a combination of vehicles, or any subconfiguration of a vehicle.

2.2/ Ontario Bridge Formula

Through an in-depth study, an operational level of load-carrying capacity of bridge structures in Ontario, designed in accordance with the existing AASHTO Standards, was established [2]. This load level, commonly known as the "Ontario Bridge Formula", became part of The Highway Traffic Act [3] in 1971. Through this formula, axle weight control in heavy vehicles was introduced in Ontario and it became possible to increase the maximum gross vehicle weight limits significantly.

However, the field staff had difficulty in checking vehicle weights using this formula, thus making it extremely difficult to enforce. To improve the enforceability of the Bridge Formula Law it was replaced in the Act in 1978 by a set of simplified Tables developed on the basis of the Ontario Bridge Formula. At the same time the formula was revised to allow about 10% higher axle weights while keeping the gross weight limits similar to the original formula.

The revised Ontario Bridge Formula is an exclusive function of the equivalent base length:

$$W_m = 10.0 + 3.0\ B_m - 0.0325\ B_m^2 \qquad (2)$$

Where W_m is the maximum permissible weight on a group of axles in thousand kilograms and the equivalent base length, B_m is expressed in metres. The formula can be applied to a vehicle, combination of vehicles, or any subconfiguration of a vehicle.

The Ontario Bridge Formula is plotted on Weight vs. Equivalent Base Length Diagram in Figure 2. For vehicles with legal overall length limit of 21 m, the practical limit for the equivalent base length is 25 m. The figure illustrates that beyond this intended limit of use the Ontario Bridge Formula reaches an apex at B_m = 46.16 m and then falls off. Due to this relatively low apex of 79 230 kg, the Bridge Formula cannot be used directly in regulating overlength/overweight vehicles for transporting long prefabricated members.

2.3/ Basis for Overweight Permit Vehicle Control

The oversize/overweight permits are issued under the following classes [4],

1. Single Trip Permit (ST)
2. Annual Permit (A)
3. Project Permit (P)
4. Mobile Homes (M)

Mobile homes are issued permits for oversize only, the weights being within the legal limits prescribed by the Highway Traffic Act. For the other three classes, the basis of the overweight permit guidelines [5] is:

(a) From bridge considerations, the design loading for the Ontario Highway Bridge Design Code [6]. This loading is a 71 400 kg vehicle model at a level of loading based on the Ontario Bridge Formula plus 10 000 kg. This loading level is given by the following equation:

$$W_0 = 20.0 + 3.0\ B_m - 0.0325\ B_m^2 \qquad (3)$$

where W_0 is expressed in thousand kilograms.

This loading level is shown in Figure 2 as a curve parallel to the Ontario Bridge Formula, and displays similar behaviour as the OBF.

(b) From pavement considerations, an overweight of 50% for single trip permits and 25% for the multi-trip permits in excess of the Ontario Bridge Formula. These criteria generally govern the axle weights. The limit for Annual and Project Permit is shown in Figure 2. For single axles ($B_m = 0$), the limit is 12 500 kg.

It was decided to adopt a maximum gross vehicle weight limit of 70 000 kg for the Single Trip and the Project Permits. Since the vehicle with Annual Permits travels without escort, with other normal traffic on routes and with loads not predetermined, a lower gross vehicle weight limit of 64 000 kg similar to the legal limit was adopted.

3/ TWO VEHICLE CONCEPT

The Two Vehicle Concept was first developed by P. Csagoly and A. Agarwal in 1973 [7]. However, the original criteria were modified during subsequent years and this report contains the modified requirements for the Two Vehicle Concept.

Tailgating among the commercial vehicles is an undesirable activity and as such is not encouraged by the Ministry. It nevertheless occurs frequently. The photographs in Figure 3 illustrate the phenomenon of tailgating.

There are many factors which lead to the truck driver's decision to tailgate:

1. Drivers associated with the same company tend to form convoys.
2. Tired drivers tend to follow another vehicle, relying on the lead driver to make many of the driving decisions.
3. Bulky transport vehicles travelling at high speed form an area of low pressure behind them creating a draught. Drivers sometimes tailgate to take advantage of this draught and save on fuel.

Let us consider the tailgating situation using vehicles loaded to the legal limits. Some of the example vehicle configurations are shown in Figure 4. Each of these vehicles is loaded to the legally permissible weights in accordance with the vehicle weight tables in the Highway Traffic Act. Although precise measurements on the clear bumper-to-bumper distance between vehicles are not available, it appears from the photographs that the clear distance could be as low as 6.0 to 8.0 m. In considering the total overhang of the vehicle body beyond the first and the last axles in the range of 1.5 to 2.0 m, it is assumed, for analytical purpose, that the minimum clear distance between the last axle of the leading vehicle and the first axle of the tailgating vehicle is 10.0 m.

A tailgating situation can be created by placing any two vehicles shown in Figure 4 at a predetermined clear distance. Three clear distances,

10.0 m, 15.0 m and 20.0 m are considered. For each combination, equivalent base length is determined using equation (1). Results of this analysis are summarized in Table 1. The six cases in Table 1 are plotted in Figure 2 for a clear distance of 10.0 m. This Figure illustrates that tailgating cases fall well above the Ontario Bridge Formula curve for $B_m > 35.0$ m.

Although such vehicle combinations do seem to violate the Bridge Formula, the bridge structures of the provincial highway system do not appear to exhibit distress associated with these overloads. Lack of apparent damage suggests that further investigation is necessary and a potentially acceptable method of evaluating long oversize/overweight vehicles should be developed. Within the "Two Vehicle Concept," the overlength vehicle carrying long indivisible payloads and consisting of a separate front and rear carrier unit could be considered as two separate vehicles. This imaginary "division" of the vehicle, permits its movement provided it satisfies certain requirements as developed under this concept.

3.1/ Limiting Criteria

Although the Two Vehicle Concept would be used for single trips or for the duration of the projects, it involves large loads and theoretically more than a single special permit vehicle. It is therefore desirable to apply requirements of multi-trip annual permits to each of the two vehicles. The limiting criteria for the Two Vehicle Concept, therefore, are as follows:

(a) Limits of Annual Permits shall apply for each of the two vehicles. The limits on axle weight are 25% more than the legal limits, and the gross vehicle weight may be 25% or 10 000 kg, more than the Ontario Bridge Formula, whichever is less. Maximum gross vehicle weight limit of each of the two vehicles shall be 64 000 kg.

(b) Total gross vehicle weight of the vehicle combination shall not exceed 120 000 kg.

(c) Force effects in bridges due to the full vehicle combination shall not exceed the effect of 70 000 kg weight uniformly distributed over a distance of 21.83 m. This weight limit represents largest gross vehicle

weight permissible under Special Permits on single vehicles by virtue of Equation (3).

3.2/ Analytical Development

Requirements for the Two Vehicle Concept are derived by examining the maximum bending moments caused by the vehicle combination in a simply supported bridge. Figure 5 shows such a bridge loaded by an oversize/overweight permit vehicle carrying a long prefabricated component. Total weight on the front and the rear vehicle units are W_1 and W_2, respectively, at a distance D between the centres of gravity of the two units. For this derivation it is assumed that

$$W_1 > W_2$$

The weights W_1 and W_2 on the two units can be uniformly distributed over equivalent base lengths B_1 and B_2 respectively, and centrally located with respect to the centre of gravity of each vehicle unit. These equivalent base lengths are determined using Equation (1), and, of course,

$$W_1 \leq 20.0 + 3.0\, B_1 - 0.0325\, B_1^2 \qquad (4)$$

and $$W_2 \leq 20.0 + 3.0\, B_2 - 0.0325\, B_2^2 \qquad (5);$$

where W_1 and W_2 are expressed in tonnes (kg x 1000) and B_1 and B_2 are given in metres.

Let us determine bending moment at a distance αL from the left hand support, where L is the span length in metres. To obtain maximum moment at any point, the larger of the two loads should be placed over the point as shown in Figure 5. The influence line ordinates are expressed as follows:

$$\eta_1 = (1-\alpha)x \tag{6}$$

$$\eta_2 = \alpha[L-x-B_1] \tag{7}$$

$$\eta_3 = \alpha[L-x-B_1/2 + B_2/2-D] \tag{8}$$

$$\eta_4 = \alpha[L-x-B_1/2 - B_2/2 - D] \tag{9}$$

$$\eta_m = \alpha(1-\alpha)L \tag{10}$$

Using these ordinates, the bending moments due to loads W_1 and W_2 are given as M_1 and M_2, respectively, thus:

$$M_1 = \frac{W_1}{2B_1}\left[-\alpha B_1^2 + 2\alpha B_1 (L-x) - (\alpha L - x)^2\right] \tag{11}$$

$$M_2 = \frac{W_2\alpha}{2}\left[2L - 2x - B_1 - 2D\right] \tag{12}$$

Therefore, the total moment at the location "αL" can be expressed as:

$$M_\alpha = M_1 + M_2 \tag{13}$$

The position of the two vehicles for maximum moment at location "αL" can be determined by:

$$\frac{dM\alpha}{dx} = 0, \text{ resulting in:} \tag{14}$$

$$x = \alpha (L - B_1) - \alpha B_1 \frac{W_2}{W_1}$$

Substitute for x from Equation (14) into Equation (11) and (12), we obtain:

$$M_\alpha = W_1 \eta_m \left[1 - \frac{B_1}{2L}\right] + \frac{\alpha^2 B_1 W_2^2}{2W_1} + \alpha W_2 \left[(1-\alpha) L + (\alpha - 1/2)B_1 - D\right] \tag{15}$$

Location of the point of maximum moment is determined by:

$$\frac{dM_\alpha}{d\alpha} = 0, \text{ resulting in:}$$

$$\alpha = \frac{1}{2}\left[\frac{2L - B_1 + r\,(2L - B_1 - 2D)}{2L - B_1 - r^2 B_1 + 2r\,(L - B_1)}\right] \qquad (16)$$

Where:

$$r = \frac{W_2}{W_1}$$

Substituting for α from Equation (16) into Equation (15), the absolute maximum value of bending moment is obtained:

$$M_{max} = \frac{W_1}{8}\,\frac{[2L - B_1 + r\,(2L - B_1 - 2D)]^2}{[2L - B_1 - r^2 B_1 + 2r\,(L - B_1)]} \qquad (17)$$

The above maximum bending moment value should not exceed the bending moment caused by a single heaviest project permit vehicle with total weight, W_s equal to 70 000 kg and equivalent base length, B_s of 21.83 m. Thus:

$$M_{max} \leq \frac{W_s L}{4}\left[1 - \frac{B_s}{2L}\right] \qquad (18)$$

Simplification of Equation (18) gives the minimum value of distance, D, between the centres of gravity of the two vehicles as follows:

$$D \geq \frac{1}{2r}\left[R - \sqrt{\frac{W_s\,(2L - B_s)\,Q}{W_1}}\right] \qquad (19)$$

where:

$$R = (r + 1)\,(2L - B_1) \qquad (20)$$

$$Q = 2L - (1 + r^2)\,B_1 + 2r\,(L - B_1) \qquad (21)$$

Application of Equation (19) reveals that the value of D increases with span length L for practical ranges of span length. However, for very long span lengths, the effect of more than a single vehicle on the bridge

becomes more important. Very long spans need not therefore be considered for evaluation of the Two Vehicle Concept. After due consideration it was decided to develop a chart for permit evaluation using a span length of 60 m. To reduce the number of parameters for practical use, a conservative approach was adopted by taking B_1 as the minimum permissible equivalent base length for load W_1 given by Equation (3) as follows:

$$B_1 = 46.15 - \sqrt{2745.6 - 30.77\ W_1} \qquad (22)$$

Figure 6 contains a chart for determining the minimum required distance D as a function of weights W_1 and W_2 on the basis of a span length of 60 m. A maximum combined weight of 120 000 kg is adopted.

3.3/ Worked Example

The following example illustrates the method of calculating the minimum distance D for a vehicle combination transporting a long prestressed concrete girder weighing 90 000 kg. The relevant data are:

$B_1 = 16.50$ m, $B_2 = 11.00$ m

$W_1 = 58\ 890$ kg, $W_2 = 47\ 900$ kg

$L = 60.00$ m

Using the above values:

$r = W_2/W_1 = 0.8134$

$R = (r + 1)\ (2L - B_1) = 187.69$ m

$Q = 2L - (1 + r^2)\ B_1 + 2r\ (L - B_1) = 163.35$ m

Now noting that:

$W_S = 70\ 000$ kg and $B_S = 21.83$ m,

we obtain from Equation (19):

$D = 30.51$ m.

Figure 6 gives a value of approximately 30.7 m.

3.4/ Comparison With Tailgating Situations

For the purpose of comparing the special permit vehicles under the Two Vehicle Concept with the tailgating vehicles loaded to the legal weight limits, five vehicle combinations, (as shown in Figure 7A and 7B), are considered. In each of the combinations, the vehicle unit on the left

represents the tractor and a dolley supporting the front end of the load being carried. The vehicle unit on the right represents a self-steering trailer. Each of the vehicle units satisfies the requirements of the Annual Permit.

For each of the five combinations shown in Figure 7, centres of gravity are determined, for both the front and the rear vehicle unit. The distance D is obtained from Figure 6 for the corresponding values of W_1 and W_2. The clear spacing between the last axle of the front unit and the first axle of the rear unit is now determined and shown in Figure 7. Equation (1) is used to determine the equivalent base length of the full vehicle combination.

The five combinations are plotted in Figure 2. It can be observed that the Two Vehicle Concept vehicles are either within the W_0 curve or below the curve representing the tailgating vehicles. It provides validation to the concept according to which permit vehicles will have less effect on the bridges compared to the tailgating legal vehicles in cases where special permit limit W_0 is exceeded.

4/ CONCLUSIONS

1. The Ontario Bridge Formula adequately represents the operational load carrying capacity of a bridge only for the practical range of vehicle lengths of up to 25 m. For longer vehicles, the formula tends to underestimate the bridge capacity.

2. For overlength vehicles with overall length in excess of 25 m, a basis of permit evaluation can be developed by studying the tailgating of vehicles loaded within legal limits.

3. The 'Two Vehicle Concept' presented in this report is a simple and practical method of controlling the overweight/overlength vehicles from bridge considerations. Using this concept, it is possible to permit transportation of long prefabricated structural components and pressure vessels.

5/ REFERENCES

1. Government of Ontario, "The Highway Traffic Act and Certain Regulations", Ministry of Transportation and Communications, Ontario, 1979.

2. F. W. Jung and A.A. Witecki, "Determining Maximum Permissible Weights of Vehicles on Bridges", RR175, Research and Development Division, Ministry of Transportation and Communications, Ontario, 1971.

3. "Axle Weight Legislation made under the Highway Traffic Act and Regulations", Ministry of Transportation and Communications, Ontario, 1971.

4. "Special permits (Oversize/Overweight) Instructional Procedure Guide", Drivers and Vehicles Regional Operations Division, Ministry of Transportation and Communications, Ontario, 1977.

5. A.C. Agarwal, "Guidelines No. 2 for the Special Overweight Permits", (TRE-81-04), Policy Planning and Research Division, Ministry of Transportation and Communications, Ontario 1981.

6. "Ontario Highway Bridge Design Code, Volumes 1 and 2", Ministry of Transportation and Communications, Ontario, 1979.

7. P.F. Csagoly and A.C. Agarwal, "The Two Vehicle Concept in Regulating Overlength/Overweight Highway Vehicles", Draft Report, Research and Development Division, Ministry of Transportation and Communications, 1973.

TABLE 1
Cases of Tailgating Vehicles

Case No.	Vehicles Involved S. No.	Gross Weight (kg)	Combined Gross Weight (kg)	Clear Distance (m)	b (m)	B_m (m)
1	1	24 100	76 100	10.0	30.00	34.69
				15.0	35.00	41.13
	4	52 000		20.0	40.00	47.19
2	1	24 100	84 100	10.0	34.25	38.03
				15.0	39.25	43.74
	5	60 000		20.0	44.25	53.08
3	2	33 300	93 300	10.0	36.75	41.90
				15.0	41.75	51.42
	5	60 000		20.0	46.75	58.44
4	3	43 000	103 000	10.0	41.00	48.58
				15.0	46.00	56.67
	5	60 000		20.0	51.00	64.50
5	4	52 000	112 000	10.0	44.25	52.04
				15.0	49.25	60.74
	5	60 000		20.0	54.25	69.17
6	5	60 000	120 000	10.0	48.50	57.68
				15.0	53.50	66.73
	5	60 000		20.0	58.50	75.55

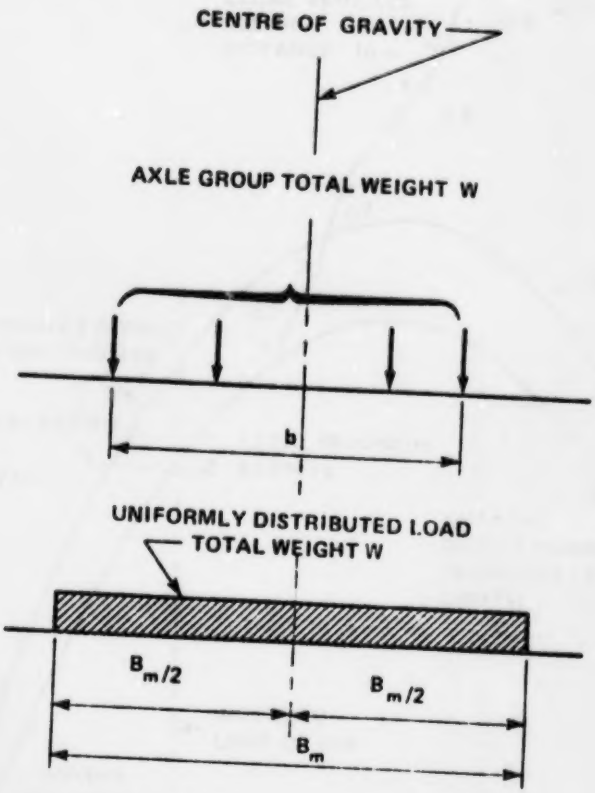


Figure 1/ Equivalent Base Length Concept

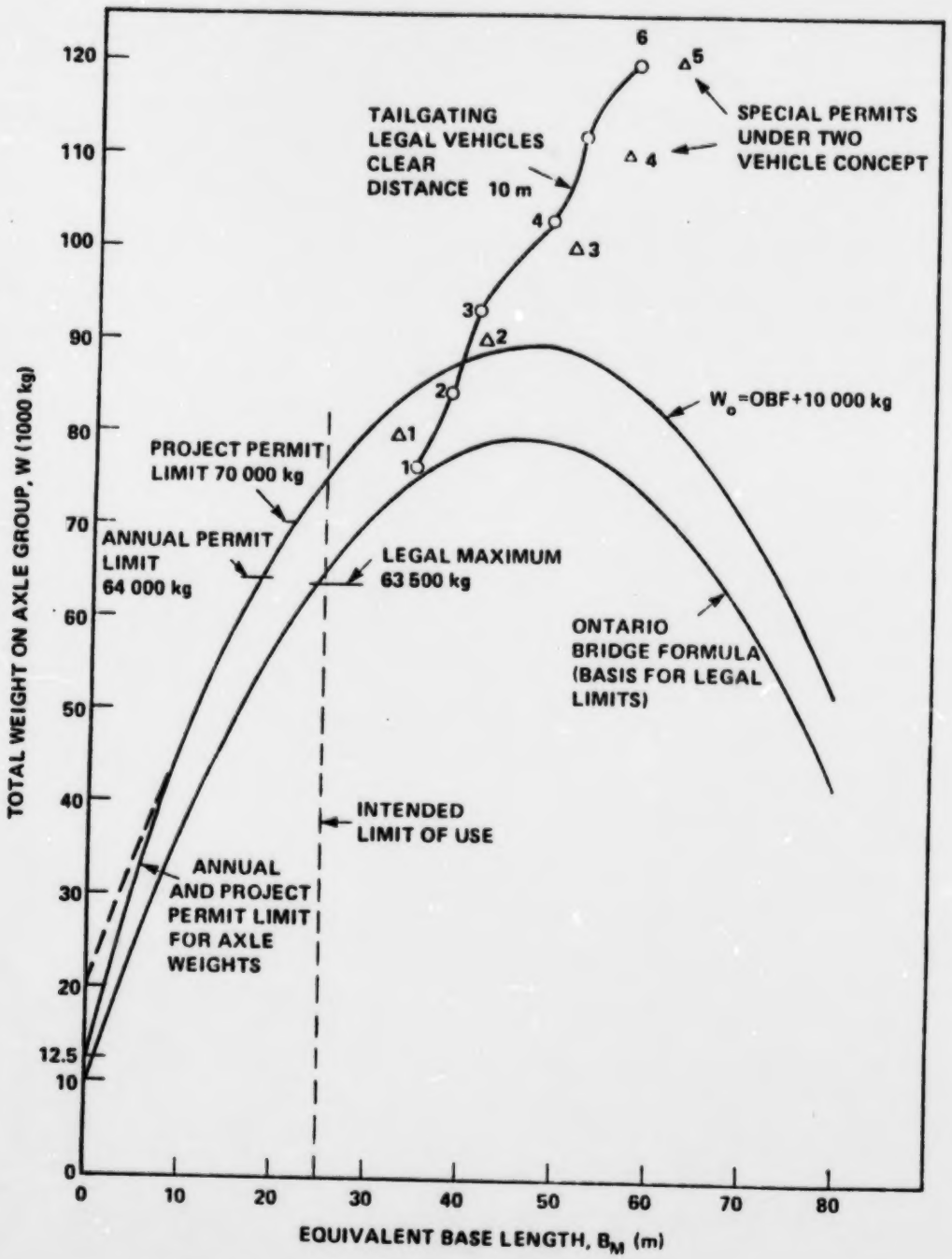


Figure 2/ Weight vs. Equivalent Base Length Diagram

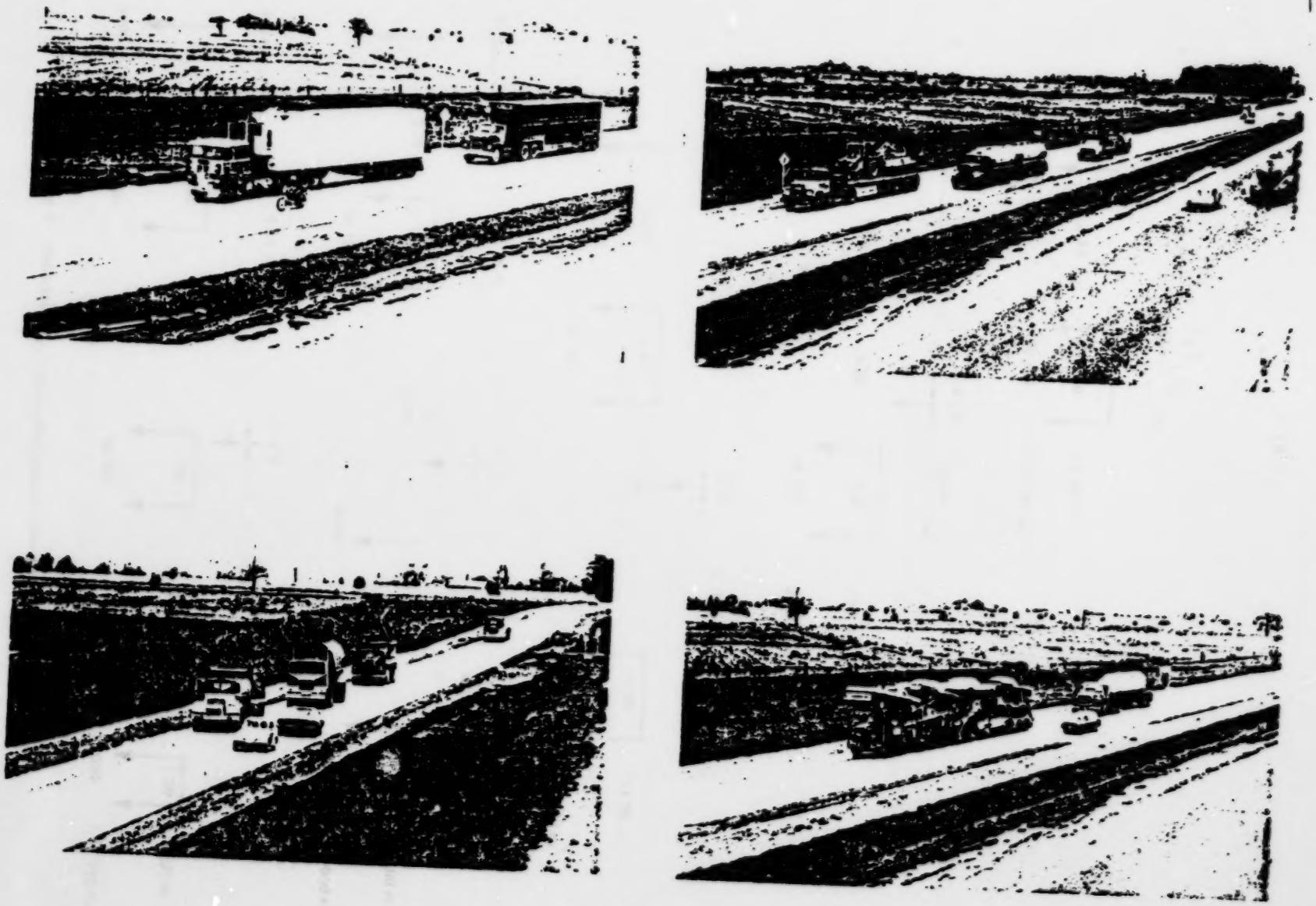


Figure 3/ Tailgating by Heavy Vehicles on the Highway

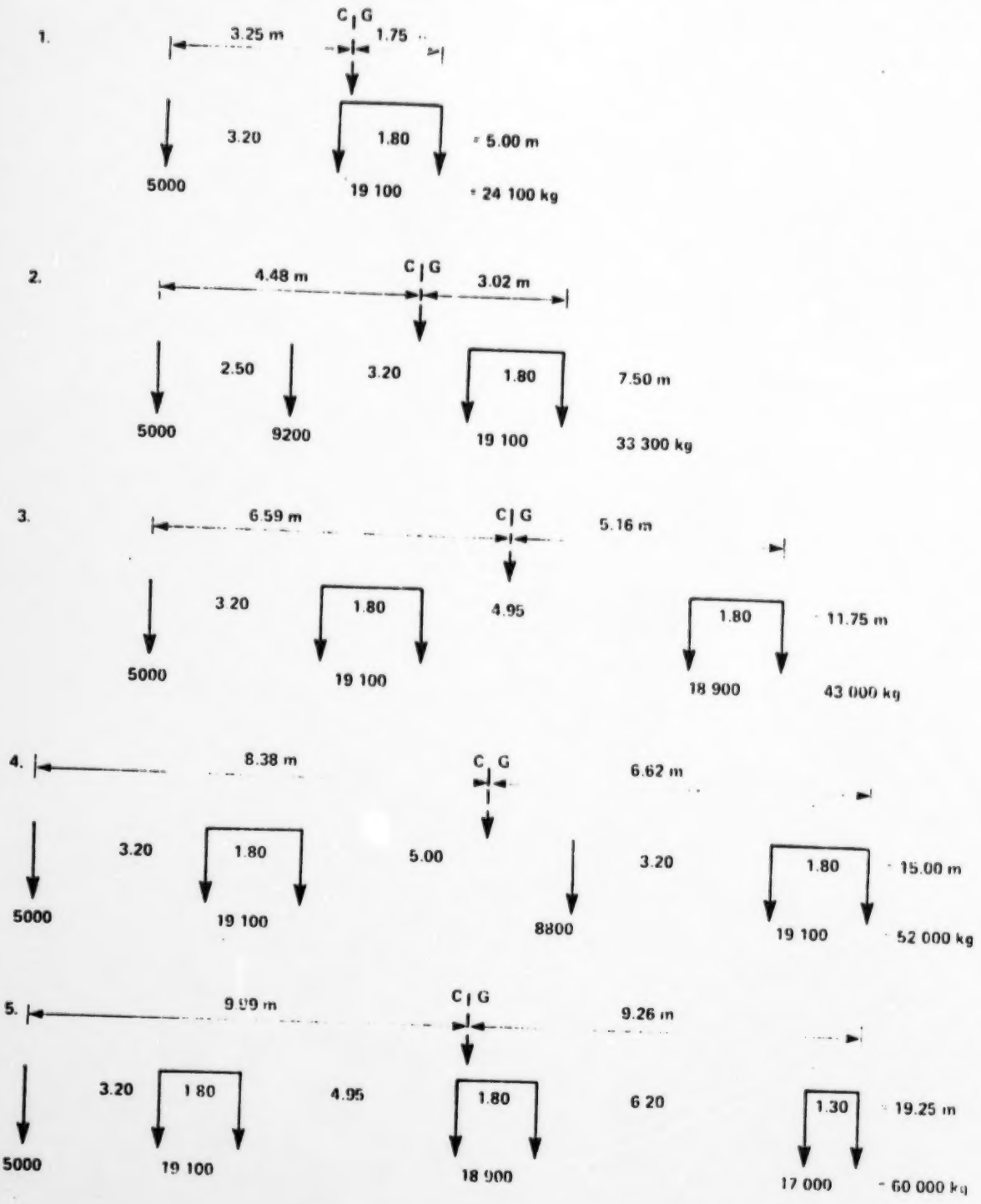


Figure 4 Vehicles With Legally Permissible Weights in Ontario

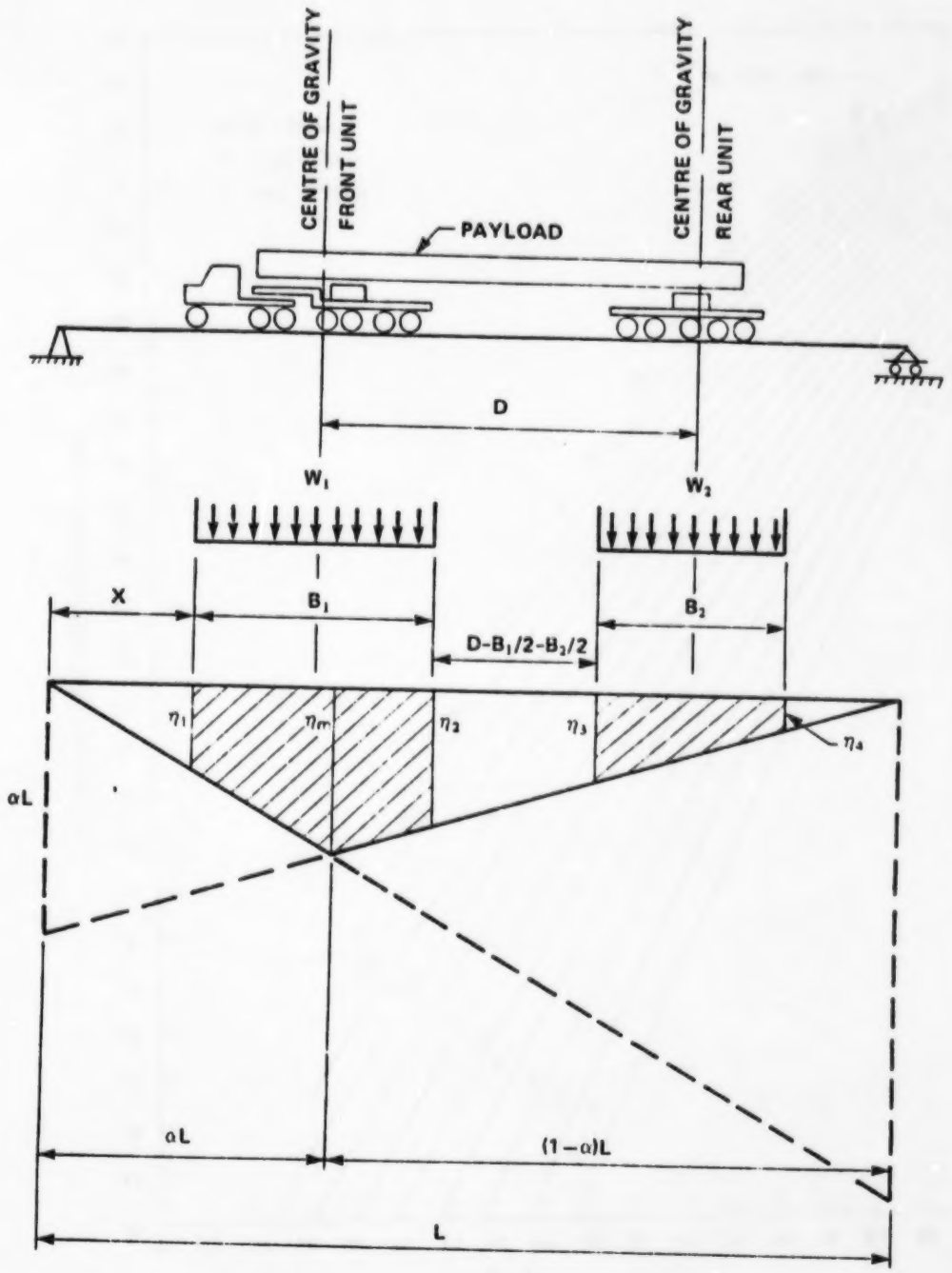


Figure 5/ The Two Vehicle Concept

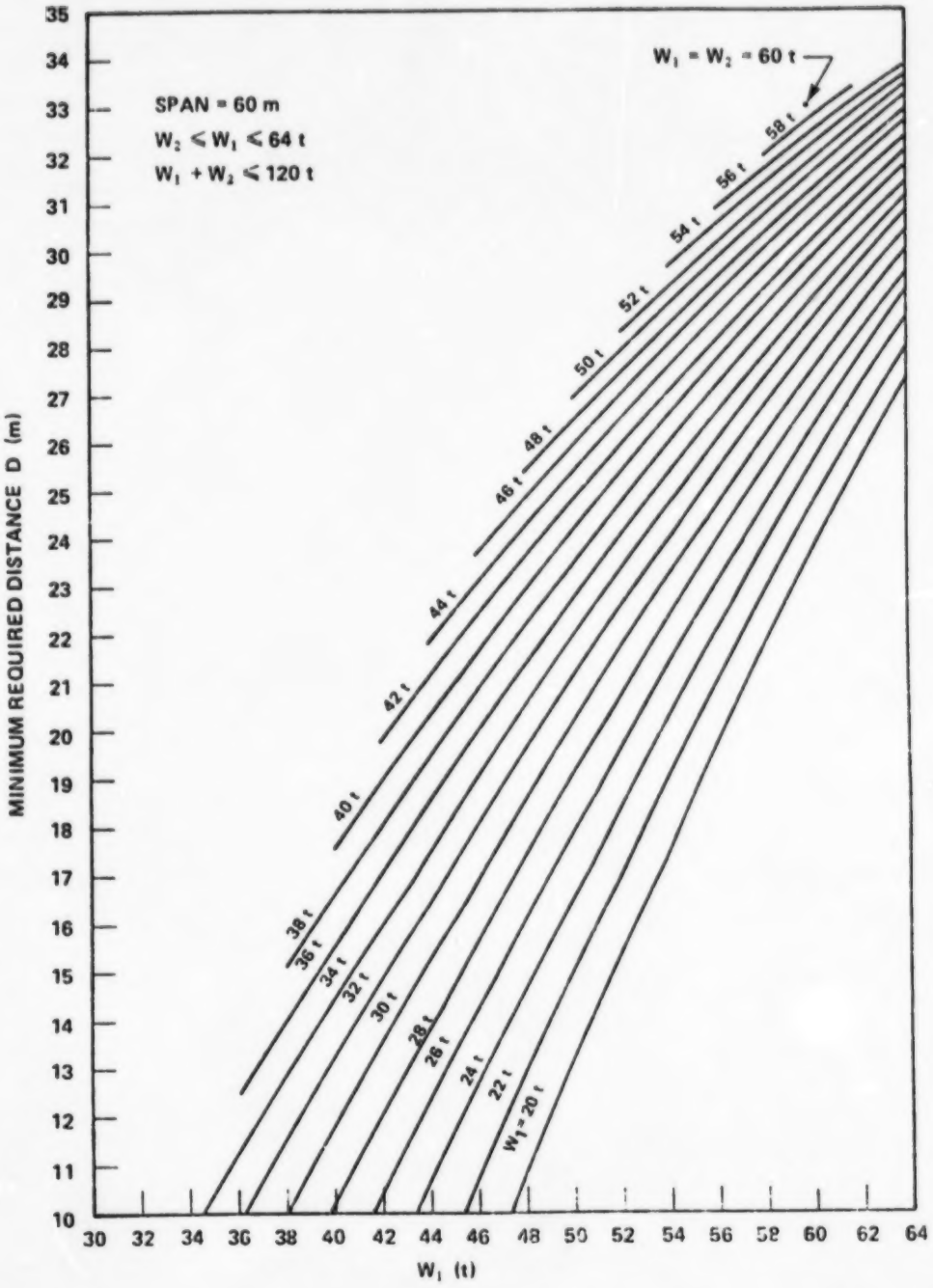
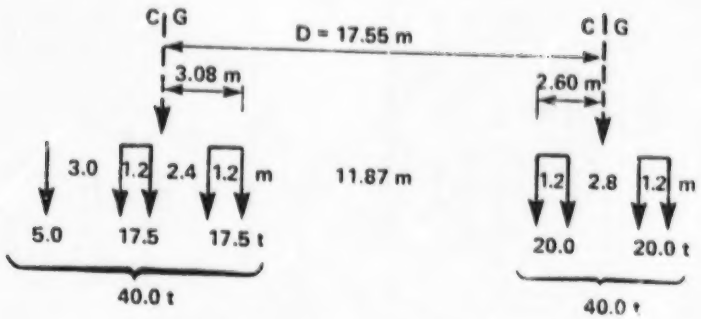


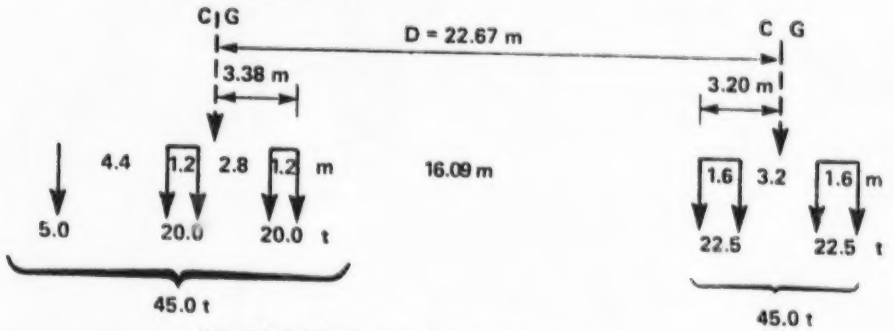
Figure 6/ Minimum Required Distance D as a Function of Weights of the Two Vehicles

1. GROSS WEIGHT 80 000 kg



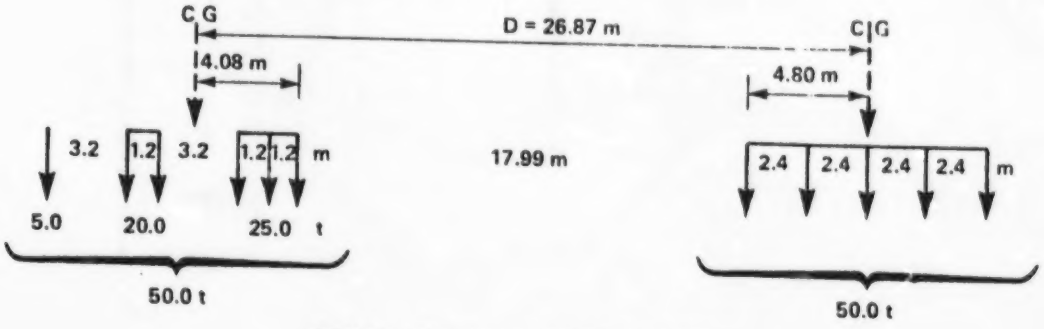
EQUIVALENT BASE LENGTH = 32.77 m

2. GROSS WEIGHT 90 000 kg



EQUIVALENT BASE LENGTH = 41.83 m

3. GROSS WEIGHT 100 000 kg



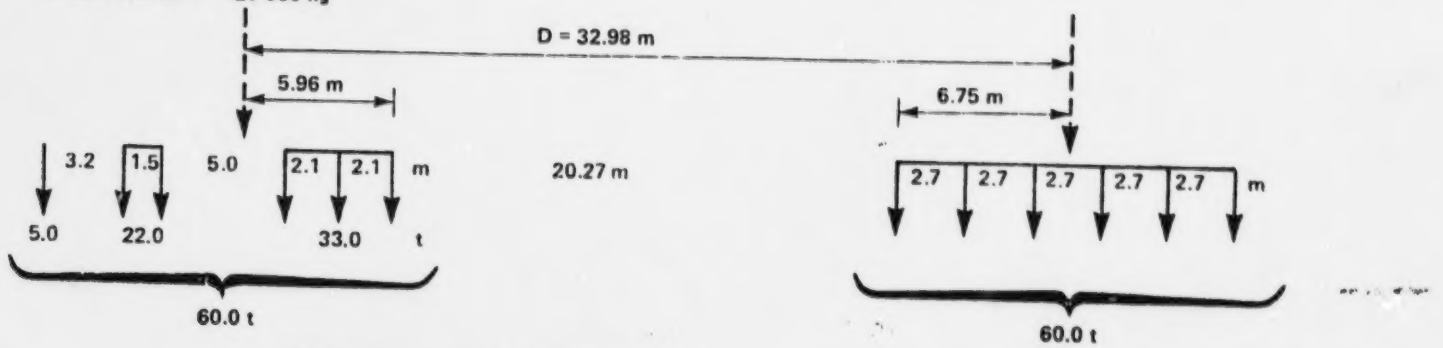
EQUIVALENT BASE LENGTH = 50.13 m

Figure 7A/ Special Permit Vehicles Allowable Under the Proposed Two Vehicle Concept

4. GROSS WEIGHT 110 000 kg

EQUIVALENT BASE LENGTH = 56.69 m

5. GROSS WEIGHT 120 000 kg



EQUIVALENT BASE LENGTH = 62.31 m

Figure 7B/ Special Permit Vehicles Allowable Under the Proposed Two Vehicle Concept